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SPACE TECHNOLOGY UNDERWATER
UNDERSEA TECHNOLOGY
AT
THE JET PROPULSION LABORATORY

James R. Edberg

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California Institute of Technology
4800 Oak Grove Drive
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The Jet Propulsion Laboratory (JPL) of the California Institute of Technology is a Federally Funded Research and Development Center (FFRDC) whose primary mission is the unmanned exploration of the Universe, under contract to the National Aeronautics and Space Administration (NASA).

Even before NASA existed, JPL and the Army's Redstone Arsenal under Werner von Braun, teamed up to launch the free world's first satellite, "Explorer I ", in January, 1958. JPL, which officially became the Jet Propulsion Laboratory in 1944, traces its beginnings to Caltech's Guggenheim Aeronautical Laboratory, where a group of graduate students under Theodore von Karman were conducting early experiments in rockets and propellants. As a result of several untoward incidents on campus, the group was "invited" to take their equipment and experiments to a more remote location. On Halloween, 1936, they fired their first successful liquid rocket engine in Pasadena's upper Arroyo Seco, a couple of miles above the Rose Bowl and the present location of JPL. It currently covers an area of 177 acres with some 150 buildings (Figure 1), a staff of around 6000 (all Caltech employees) and an annual budget exceeding a billion dollars.

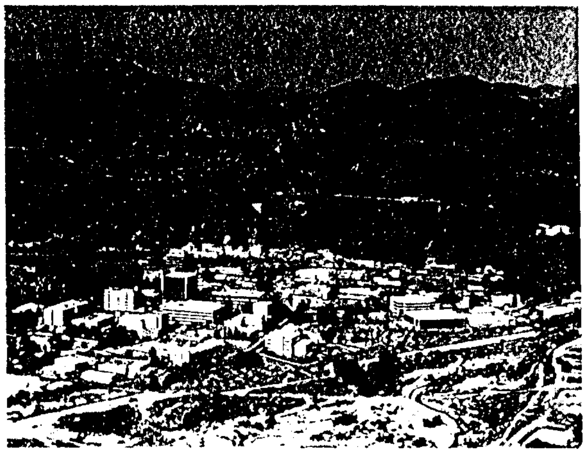

Figure 1

Because of these early Caltech experiments, the Army became interested in possible military applications 01 rockets and rocketry and began funding the von Karman group. This subsequently matured into a contractual relationship whereby Caltech would staff and operate the Jet Propulsion Laboratory under contract to the Army, This association developed the Jet Assisted Take Off (JATO) units during WW II, several high altitude sounding rockets and two tactical missiles which were deployed with U.S. Forces.

With the creation of NASA in 1958, JPL was transferred from its existing contractual relationship with the Army, to that of NASA, where it has been responsible for the Ranger, Pioneer and Surveyor explorations of the moon and the Mariner, Viking, Voyager, Mars Orbiter, Galileo, missions to all planets except Pluto, JPL has also been involved in several earth orbiting spacecraft, among them the ocean oriented "Seasat" and "Topex " In support of these missions, JPL has necessarily pioneered in the development of a variety of advanced technologies and techniques, with potential application in numerous other fields.

Explicit in the contract between NASA and Caltech is an agreement that up to one quarter of the Laboratory's total effort may be applied to non-space activities, where JPL may have a unique expertise to apply to terrestrial pro blems and where it will not be in competition with industry. JPL may not respond to RFP's, for example. These non-space activities are the province of the Technology and Applications (TAP) Directorate and it is under this TAP umbrella that the current Undersea "1'ethnology program exists.

Why Undersea l'ethnology? Unmanned space exploration requires the development and operation of sophisticated, extremely reliable vehicles, operating unattended for periods of years in remote locations and in unfamiliar and often hazardous and unknown environments and with rigid constraints on weight, power anti size. Within these constraints, it is desired to maximize the sensor complement and information return over communication channels billions of miles in length. With allowances for the differences in the operating medium, which are certainly not insignificant, the operating requirements and constraints of operations in space bear a strong resemblance to those imposed by operations in and under the oceans.

The current Undersea Technology program could be referred to as Phase 11; a similar, very successful effort existed at JPL from 1975 to 1981. As a prelude to the current effort, let me indulge in a bit of history. Discussions with the Scripps Institution of Oceanography, the U S Geological Survey and others indicated that an unmanned deep towed system incorporating digital technology would be a worthwhile initial project. The completed system, designated AOTDP for Advanced Ocean Technology Development Platform (Figure 2), was operationally very similar to the existing Scripps Deeptow in that it operated from a surface ship on a 3/4 inch diameter coaxial cable and was designed for a depth of 20,000 ft. Two significant advances were incorporated: the electronics in the submersible were all digital (adapting the Galileo spacecraft digital system and using it under water before it was used in space!) providing a quarter million bits per second data capability, and secondly, as an integral part of the system, a portable shipboard data processing and display van was provided, allowing the processing and display of acquired data in real time, a first at the time. Primary initial scientific instrumentation was two JPL developed digital side scan sonars.

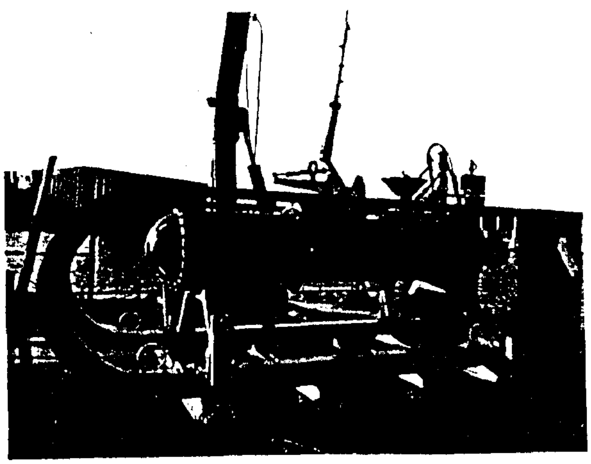

Figure 2

Other accomplishments included the development and operation of a towed, swept frequency "chirp" sonar sub-bottom profiler (Figure 3), used operationally on several cruises both

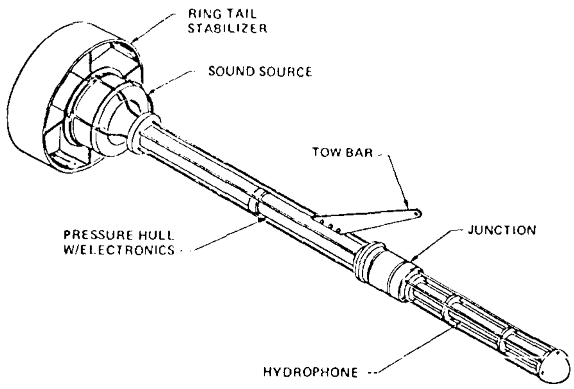

Figure 3

with NOAA and the Geological Survey; working with the English Institute of Oceanographic Sciences GLORIA sonar data and processing it into large area mosaics of the Mid-Atlantic ridge; participating in the ONR/Woods Hole High Energy Benthic Boundary Layer Experiment (HEBBLE); processing and enhancing Canada Center for Inland Waters sonar data of the U S S Hamilton resting on the bottom of Lake Erie; organizing and hosting two significant workshops/conferences, one on Underwater imaging, and a second more extensive conference, "Advanced Unmanned Underwater Systems and Instrumentation" in 1979, sponsored by JPL/Caltech, NASA, NOAA, and the Institute of Marine and Coastal Studies at the University of Southern California. The Steering Committee for that conference is shown in the table below.

STEERING COMMITTEE

James Edberg -- Co-Chairman
Jet Propulsion Labortory/Caltech
Don Walsh -- Co-Chairman
Institute of Marine& Coastal Studies/USC
Jack Cawley
NOAA -- Office of Ocean Engineering
Terry Fisher
US Geological Survey
Fred Fisher
Scripps Institution of Oceanography
William Gulizia
Jet Propulsion Laboratory/Caltech
Jack Jaeger
Tetra Tech/Hydro Products
Ivor Lemaire
Naval Ocean Systems Center, San Diego
Nelson Milder
NASA -- Code ETD-6

William Siapno
Deepsea Ventures, Inc.
Josepy Vadus
NOAA — Office of Ocean Engineering
Douglas Webb
Woods Hole (Oceanographic Institution
Robert Ballard
Woods Hole Oceanographic Institution
Thomas Hilton
Deepsea Ventures, Inc.

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Now, what about today? Current JPL technologies which appear to have potential for underwater applications include, but are not necessarily limited to:

- Digital imaging and image processing.
- Advanced power sources and systems.
- Micro electronics/micro devices.
- Teleoperators and robotics.
- High performance computing, neural networks.
- Autonomous roving vehicles.
- Navigation and control.
- Unique materials.
- Communications/data compression.
- Scientific and engineering instrumentation.
- Structural analysis.
- Simulation and testing.
- Systems engineering and complex project management.

Time and space availability preclude even a cursory discussion of each of these areas; however, let me select a few examples which may illustrate the potential which exists.

The JPL Digital Imaging Animation Laboratory (DIAL) has the ability to accept a variety of data sets and fuse them into a continuous cohesive presentation of a dynamic situation. A recent example, produced for the Oceanographer of the Navy, is a movie of Monterey Bay. Seven distinct , data sets were used, including satellite imagery, bathymetric data and two dimensional current data. The movie includes an underwater "flight" up the offshore marine canyon. Most recently, DIAL has worked with Dr. John Delaney of the University of Washington in producing a movie of topography and activity along the Juan de Fuca Ridge off the northwest Pacific Coast.

Future space missions place extreme limitations on weight, size and power. As a consequence, JPL has an extensive effort devoted to advanced power sources featuring small size, long life and increased specific energy. Current and projected performance envelopes of various types of cells are shown in Figure 4.

PROJECTED PERFORMANCE ENVELOPE
STATE OF ART **AND ADVANCED CELLS**

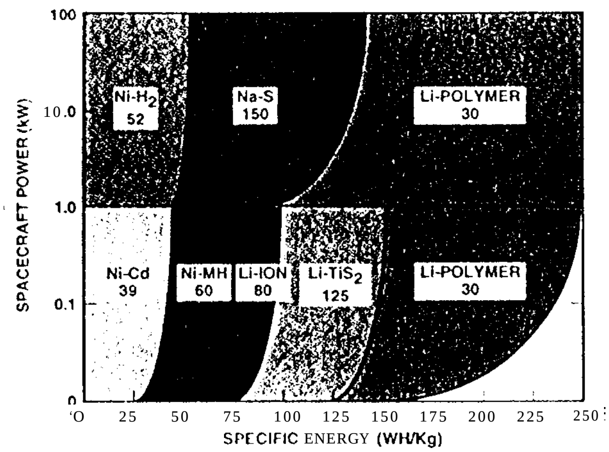

Figure 4

A double "A" $Li-TiS_2$ cell has been successfully cycled 1000 times to 50% depth of discharge at ambient temperature. Also under development is a direct methanol, liquid feed fuel cell, where a 3% methanol/water mixture is the fuel, and air (O_2) is the oxidant (Figure 5). Advantages include simplicity, start-up at room temperature and operation at 70 - 90°C, and no pollutants; as an example, a 4" x 6" cell is capable of providing 50 amps continuously at 0.4 volt and 90°C with air. Plan is to demonstrate a 1 kw fuel cell stack in less than 24 months.

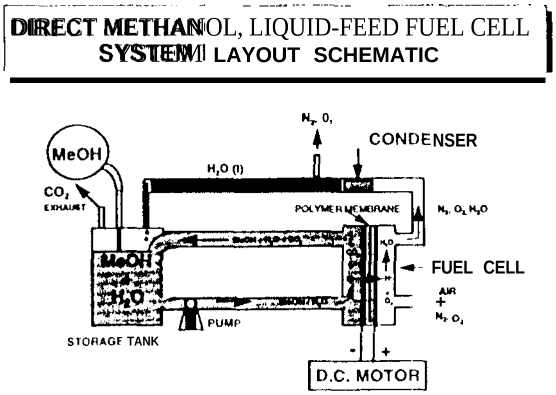

Figure 5

With the emphases on smaller, lighter, cheaper, in space as well as underwater, the JPL Space Micro-electronics program could provide significant dividends in subsurface instrumentation and operations. Devices already in various stages of development using tunneling phenomena and micro-machining, include seismometers, hygrometers, radiometers and anemometers. A hydrophore developed for the Navy is packaged in a one inch sphere (Figure 6).

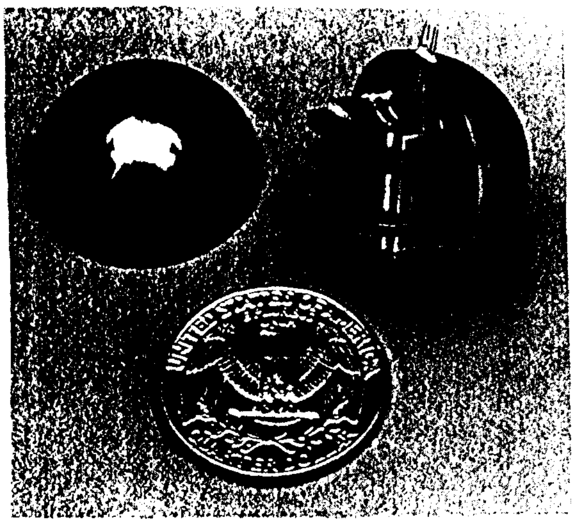

Figure 6

Also, currently under development is an extremely compact, complete micro-weather station to be deployed on the surface of Mars to measure pressure, temperature, humidity and wind velocity. Figure 7 shows several of these sensors along with a scale to indicate size.

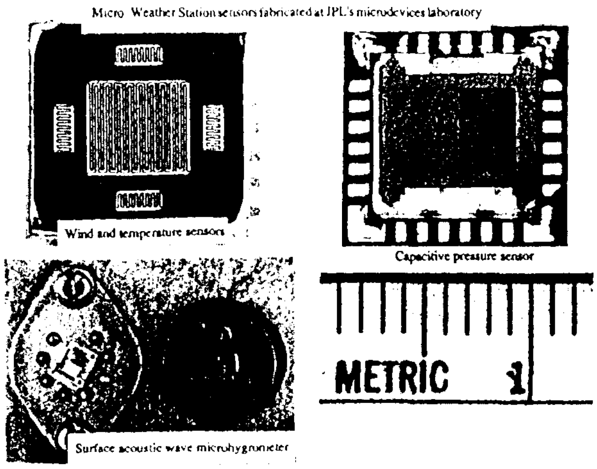

Figure 7

Teleoperator/robotic activities include a 7-degree of freedom arm being developed for NASA as a remote inspection tool for the surface of the space station; a modular 11 -degree of freedom arm approximately 2 inches in diameter capable of probing into complex and intricate spaces and an extremely precise remotely operated device for inside the eyeball surgery, with an accuracy of **10** angstroms. A remotely operated system "HAZBOT" (figure 8), developed for the JPL Fire Department, permits entry - even through locked doors - into smoke filled or gas filled rooms to determine whether conditions would be hazardous for human entry.

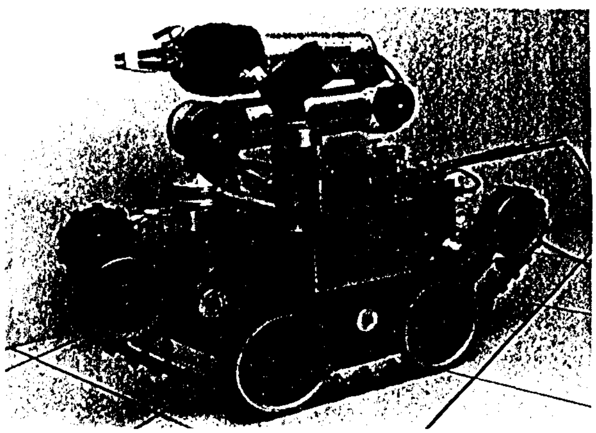

Figure 8

A small, 10kg, six-wheeled roving vehicle, the Micro-rover Flight Experiment, MFEX, (Figure 9) is being readied for deployment from a Mars surface lander in 1977 and operate semi-autonomously performing engineering and science experiments, including deployment of an alpha-proton-X-ray spectrometer.

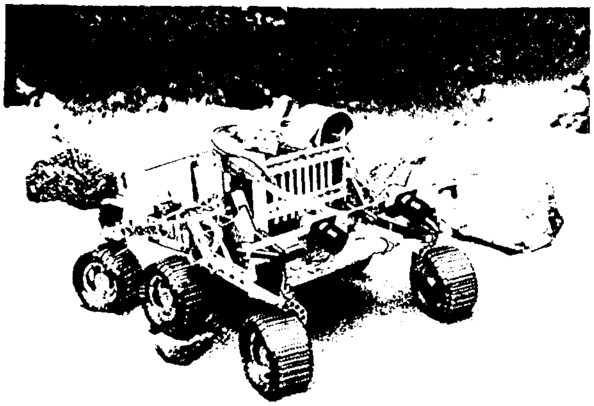

Figure 9

A prototype of this micro-rover was "road tested" in the April, 1993 issue of "Road & Track" magazine.

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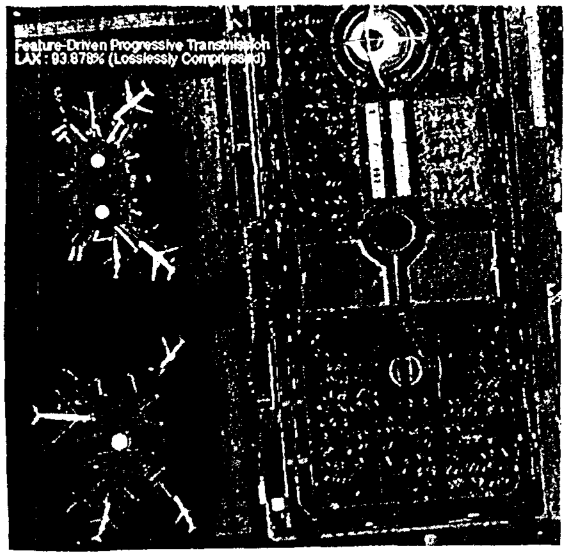

Figure 10

Figure 11 shows the same image but with only 5% of the data transmitted, a 20 to 1 compression. Given the bandwidth limitations of acoustic transmissions underwater, this compression technique might provide significantly increased information transmission over a given bandwidth.

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Of possible interest as a source for laser imaging systems is a JPL developed, diode-pumped green laser, providing more than 2 watts of average power at 532 nanometers, with an efficiency greater than 3%. Pulse repetition rates to 50KHz. It is a compact, rugged, all solid state device promising high stability and long life.

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The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of '1'ethnology, under a contract with the National Aeronautics and Space Administration.

6/14/95

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Fig 1

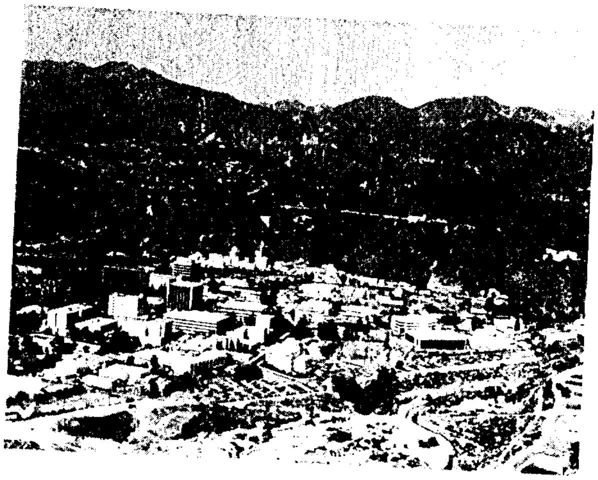
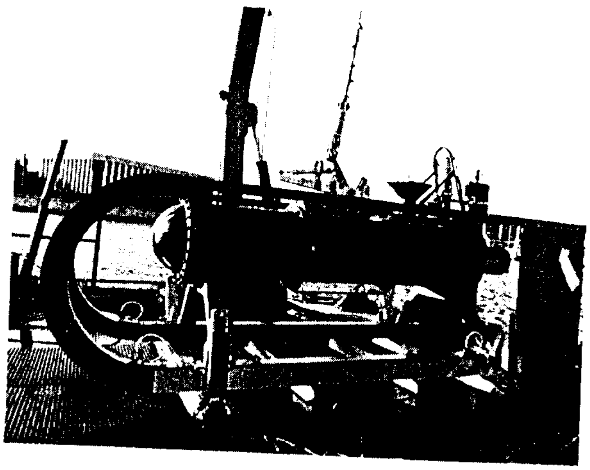


Fig 2



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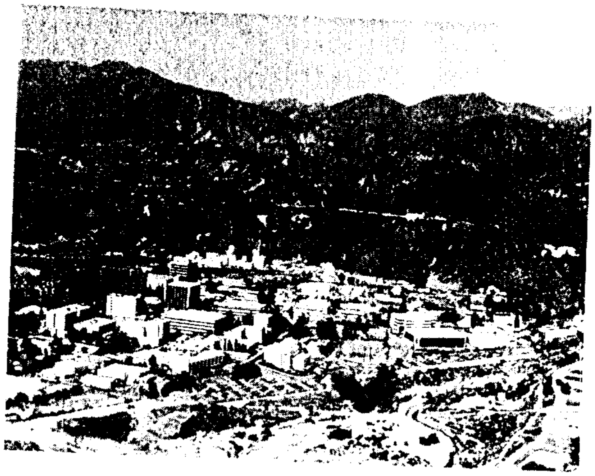

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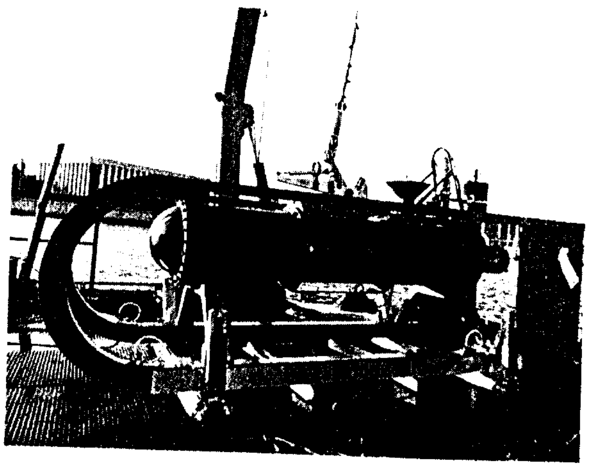


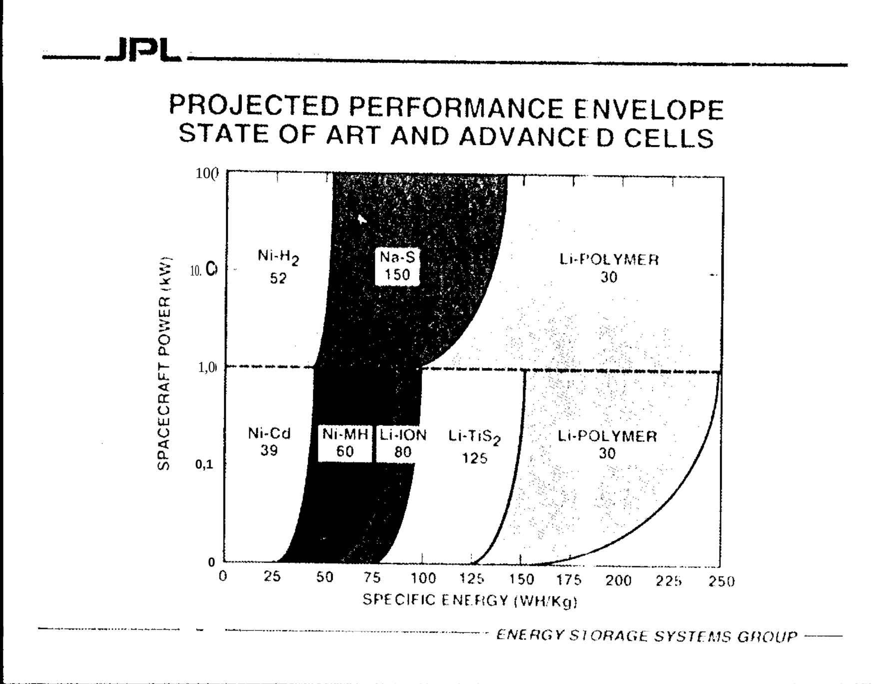
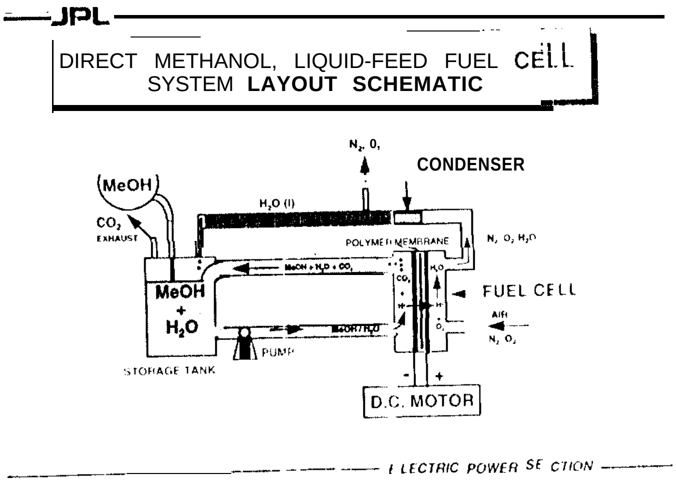

JPL
PROJECTED PERFORMANCE ENVELOPE
STATE OF ART AND ADVANCED CELLS
SPACECRAFT POWER (kW)
Ni-H2
52
Na-S
150
LI-POLYMER
30
Ni-Cd
39
Ni-MH
60
Li-ION
80
Li-TiS2
125
LI-POLYMER
30
0 25 50 75 100 125 150 175 200 225 250
SPECIFIC ENERGY (WH/Kg)
ENERGY STORAGE SYSTEMS GROUP

FIG. 4

FIG 5


JPL
DIRECT METHANOL, LIQUID-FEED FUEL CELL
SYSTEM LAYOUT SCHEMATIC
N2, O2
CONDENSER
MeOH
CO2
EXHAUST
H2O (l)
POLYMER MEMBRANE
N2, O2, H2O
MeOH + H2O
FUEL CELL
AIR
N2, O2
PUMP
STORAGE TANK
D.C. MOTOR
ELECTRIC POWER SECTION

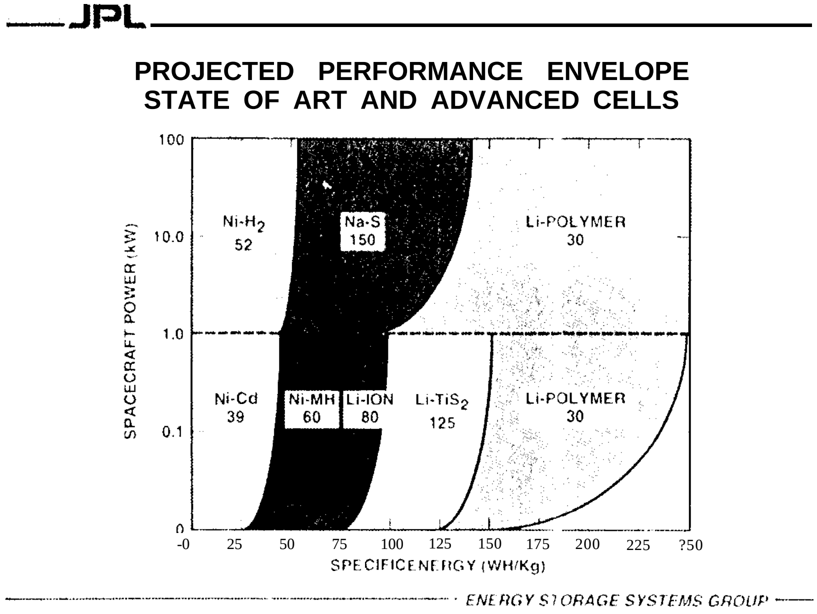

JPL
PROJECTED PERFORMANCE ENVELOPE
STATE OF ART AND ADVANCED CELLS
SPACECRAFT POWER (kW)
100
10.0
1.0
0.1
0
Ni-H_2
52
Na-S
150
Li-POLYMER
30
Ni-Cd
39
Ni-MH
60
Li-ION
80
Li-TiS_2
125
Li-POLYMER
30
-0 25 50 75 100 125 150 175 200 225 ?50
SPECIFICENERGY (WH/Kg)
ENERGY STORAGE SYSTEMS GROUP

FIG. 4

FIG 5

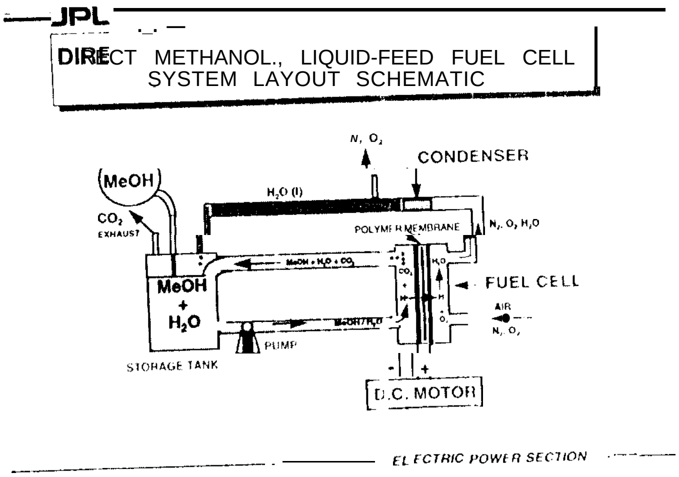
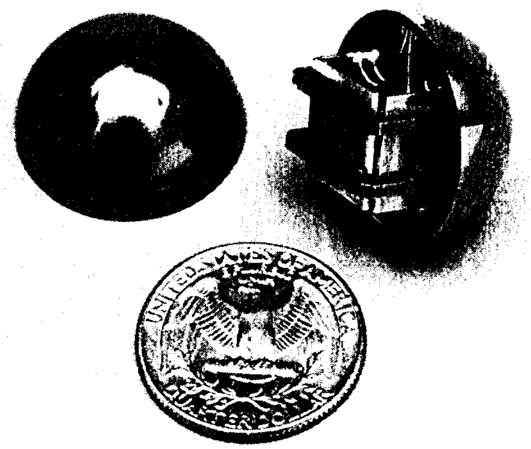

JPL
DIRECT METHANOL., LIQUID-FEED FUEL CELL
SYSTEM LAYOUT SCHEMATIC
CONDENSER
(MeOH)
CO_2
EXHAUST
H_2O (l)
POLYMER MEMBRANE
MeOH + H_2O
STORAGE TANK
PUMP
FUEL CELL
AIR
D.C. MOTOR
ELECTRIC POWER SECTION

FIG 6



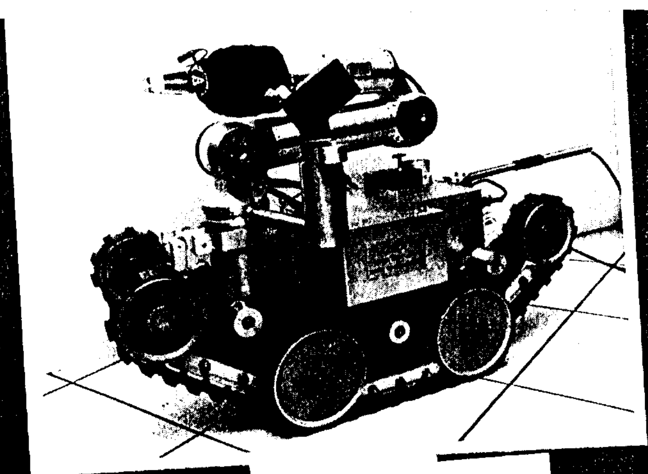
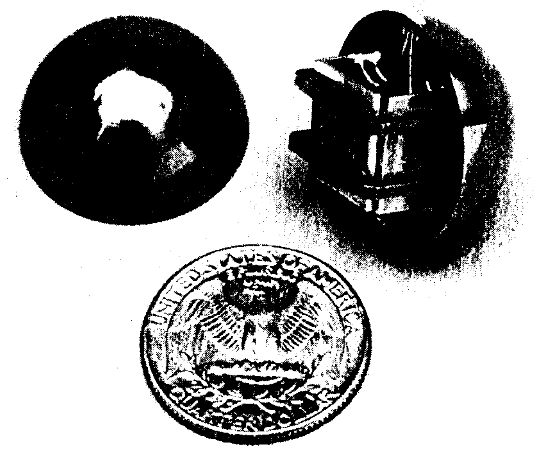


FIG 8

FIG 6



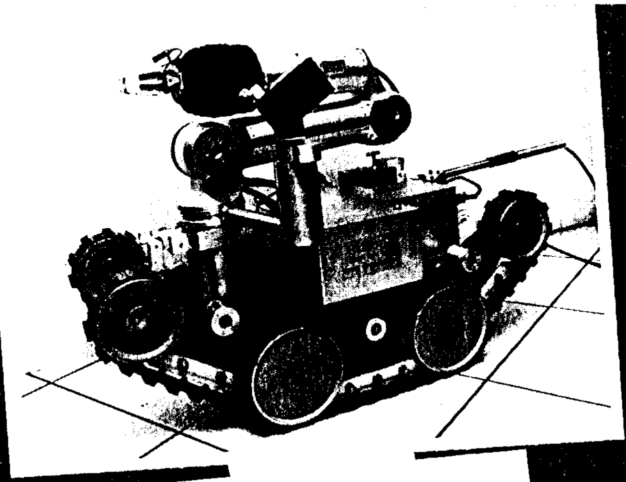


FIG 8

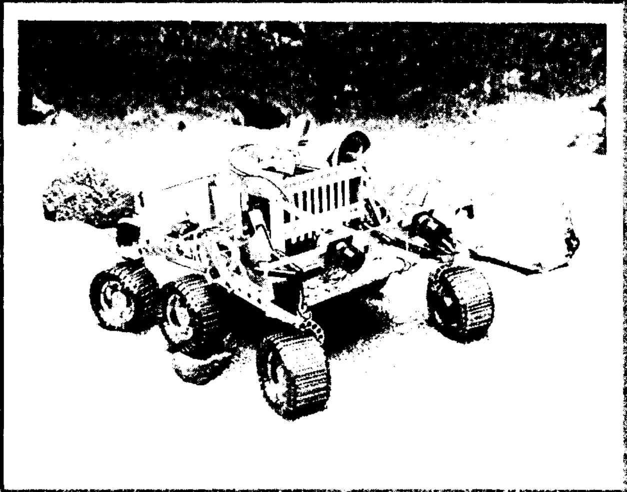


Fig. 9

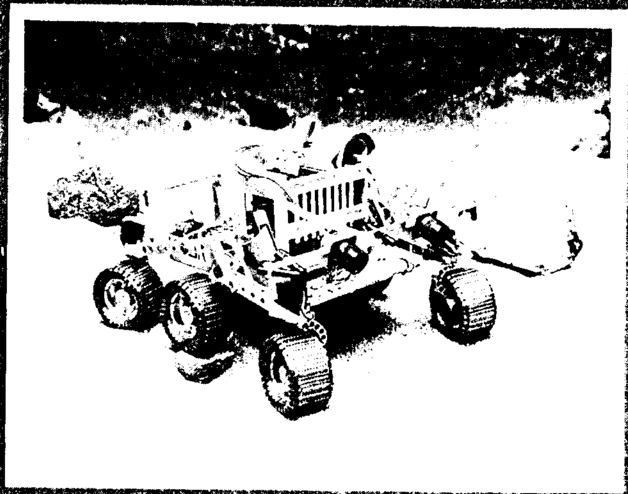


Fig. 9

FIG 10

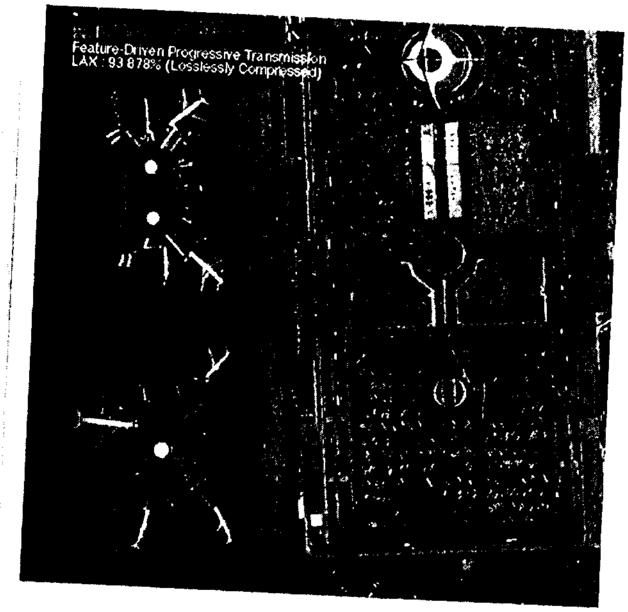

Feature-Driven Progressive Transmission
LAX : 93.878% (Losslessly Compressed)

FIG 11

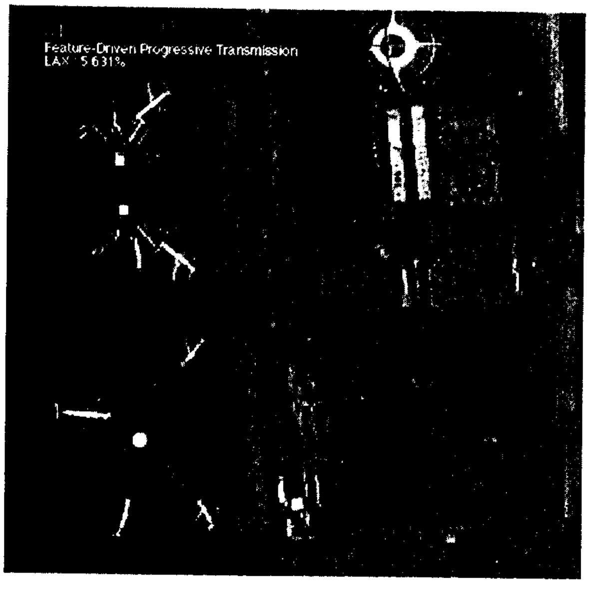

Feature-Driven Progressive Transmission
LAX : 5.631%

FIG 10

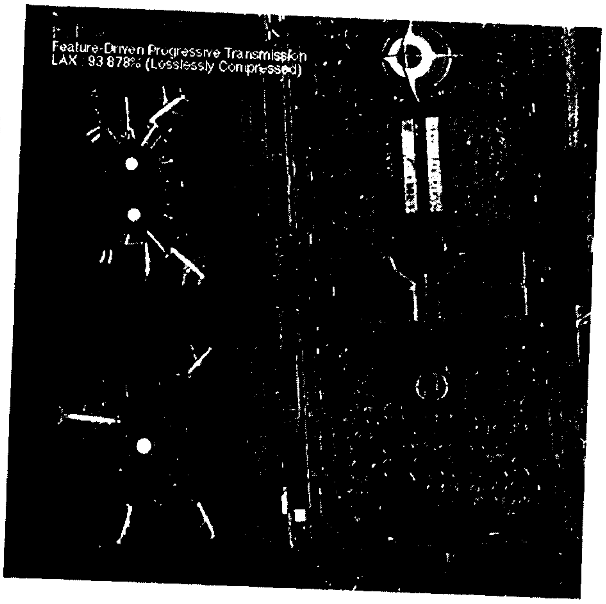

Feature-Driven Progressive Transmission
LAX 93 878% (Losslessly Compressed)

FIG 11


Feature-Driven Progressive Transmission
LAX 5 631%

TABLE 1

STEERING COMMITTEE

James Edberg -- Co-Chairman
Jet Propulsion Laboratory /Caltech
Don Walsh - Co-Chairman
Institute of Marine & Coastal Studies/LJSC
Jack Cawley
NOAA - Office of Ocean Engineering
Terry Edgar
US Geological Survey
Fred Fisher
Scripps Institution of Oceanography
William Gulizia
Jet Propulsion Laboratory /Caltech
Jack Jaeger
Tetra Tech/Hydro Products
Ivor Lemaire
Naval Ocean Systems Center, San Diego
Nelson Milder
NASA – Code ETD-6
William Siapno
Deepsea Ventures, inc.
Joseph Vadus
NOAA - Office of Ocean Engineering
Douglas Webb
Woods Hole Oceanographic Institution
Robert Ballard
Woods Hole Oceanographic Institution
Thomas Hilton
Deepsea Ventures, Inc.

WORKSHOP PROSPECTUS

The Jet Propulsion Laboratory (JPL) of the California Institute of Technology and the Institute of Marine and Coastal Studies (IMCS) of the University of Southern California are co-hosting a "shirt-sleeves" style workshop designed to bring together the expertise of the academic, governmental, and industrial communities to explore current and projected national needs and priorities for unmanned underwater vehicle systems and instrumentation. The expertise assembled in workshop panels are to assess and specifically define the problem areas, establish measurement requirements, instrument packages and basic vehicle requirements. The role of unmanned underwater vehicles is to be assessed in its application to the most pressing national needs in the fields of exploration, monitoring, observation and sampling of the deep ocean environment.

Five "shirt sleeves" working panels have been established to focus on several of the most pressing national needs:

Waste Disposal and Monitoring in the Ocean -